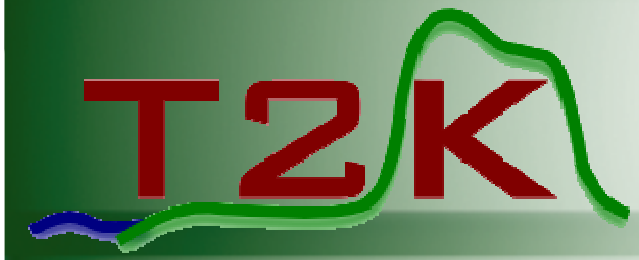

The T2K CCQE selection and prospects for CCQE, NC cross section measurements

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for the T2K Collaboration

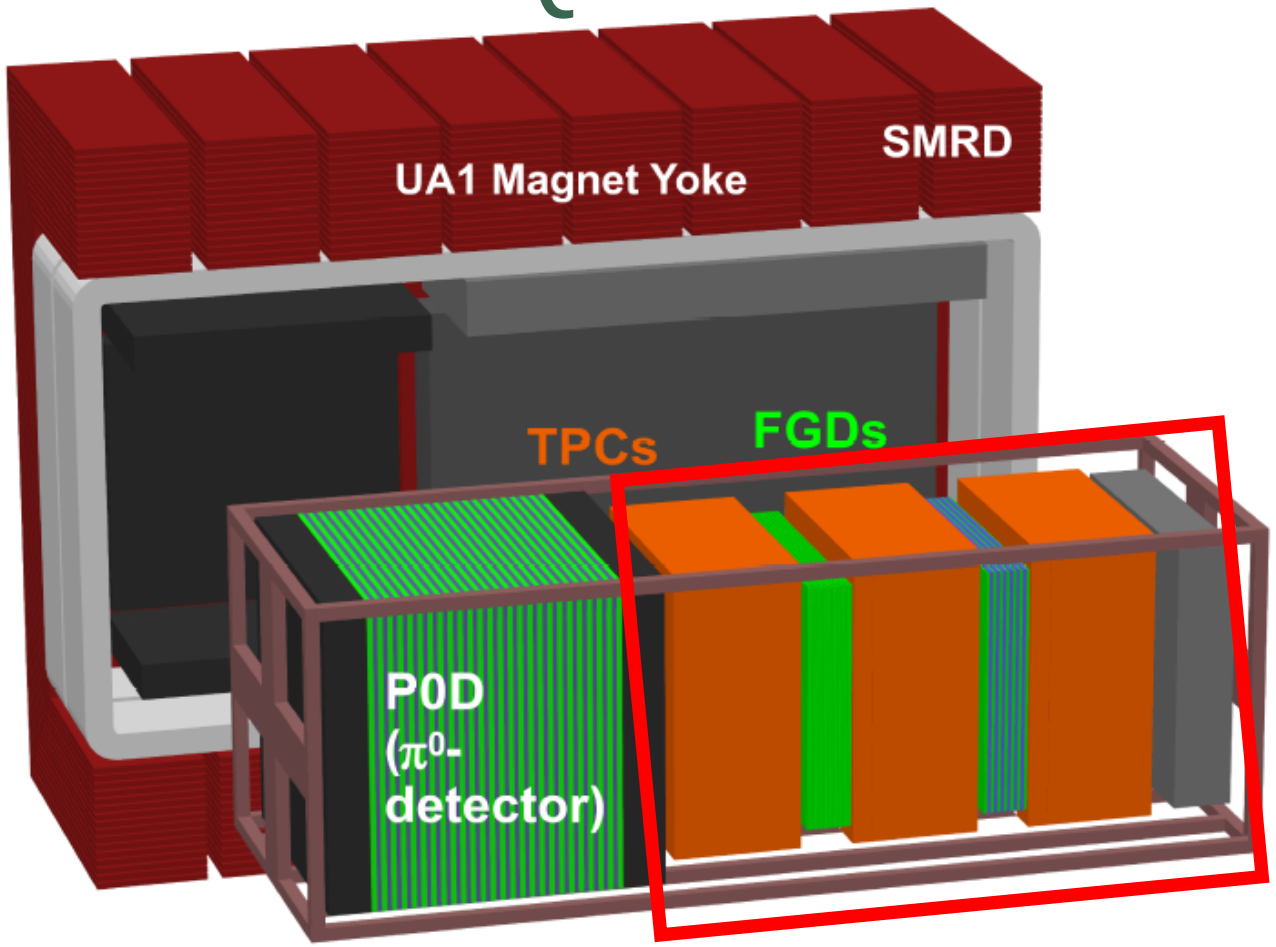
NuInt2012, Rio De Janeiro

Colorado State University

Overview

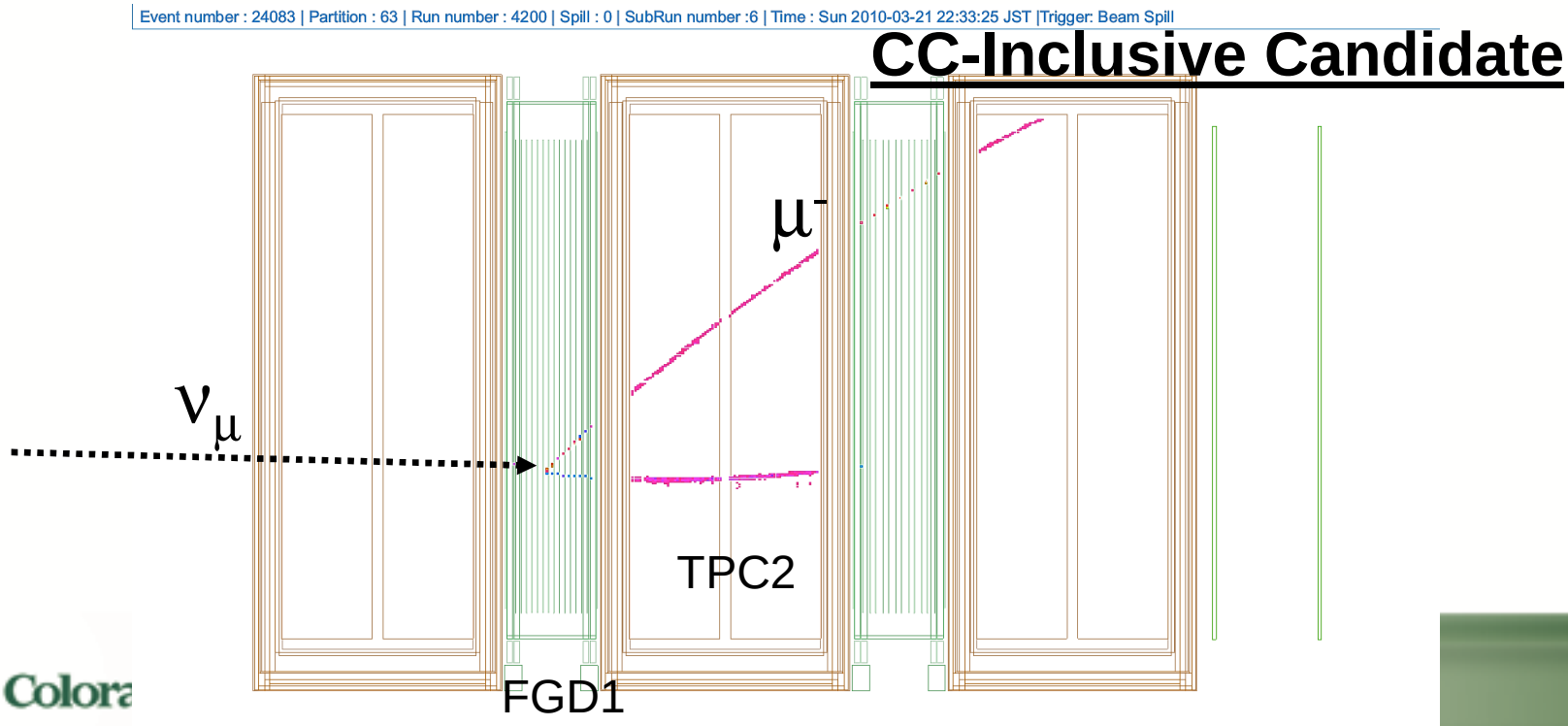
- T2K CCQE Results
  - Selection
  - Use of sample in fits for oscillations and cross-section uncertainties
  - Future work
- T2K NCE MC Study
  - Basic idea behind analysis
  - Selection criteria
  - MC predictions

T2K CCQE Results



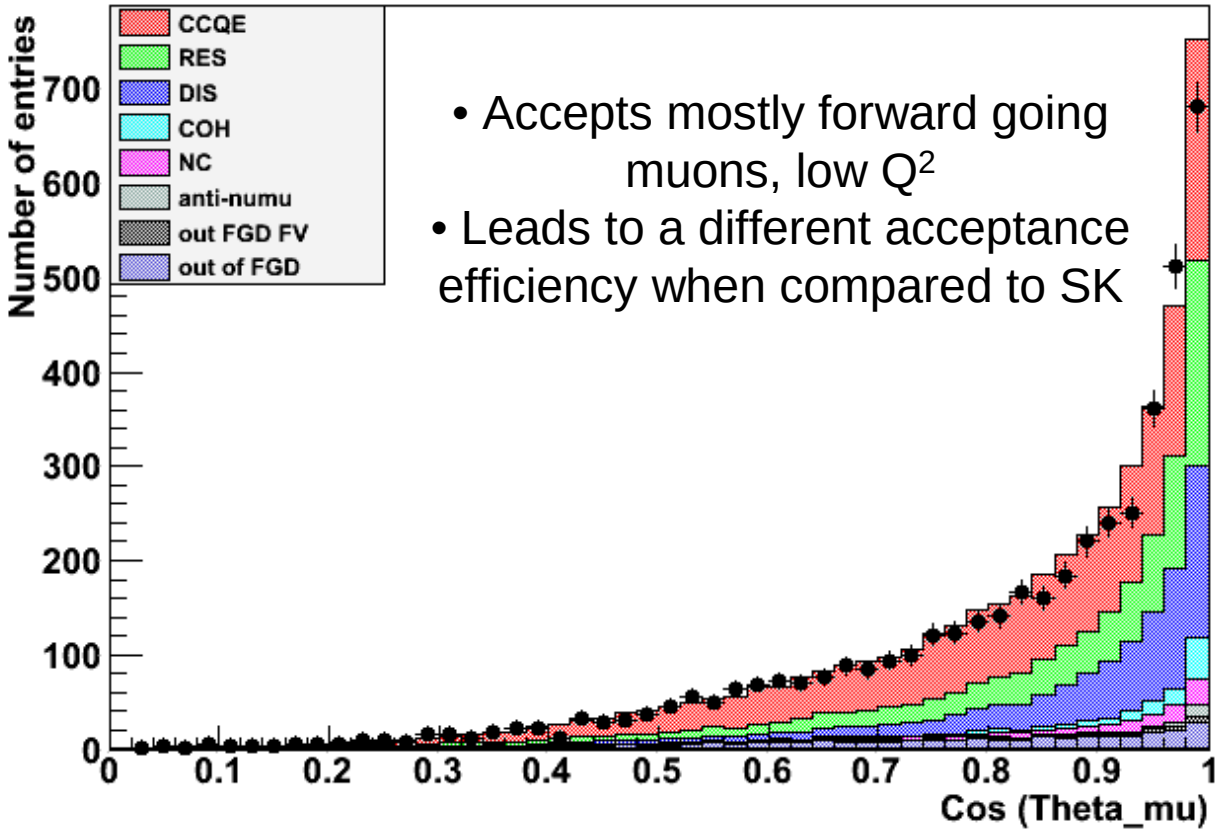
T2K CC-Inclusive Selection

- At least 1 negatively charged track in TPC2
- Track starts within the fiducial volume of FGD1
- dE/dx compatible with muon hypothesis in TPC
- No backwards tracks allowed
- Vertex is the track start



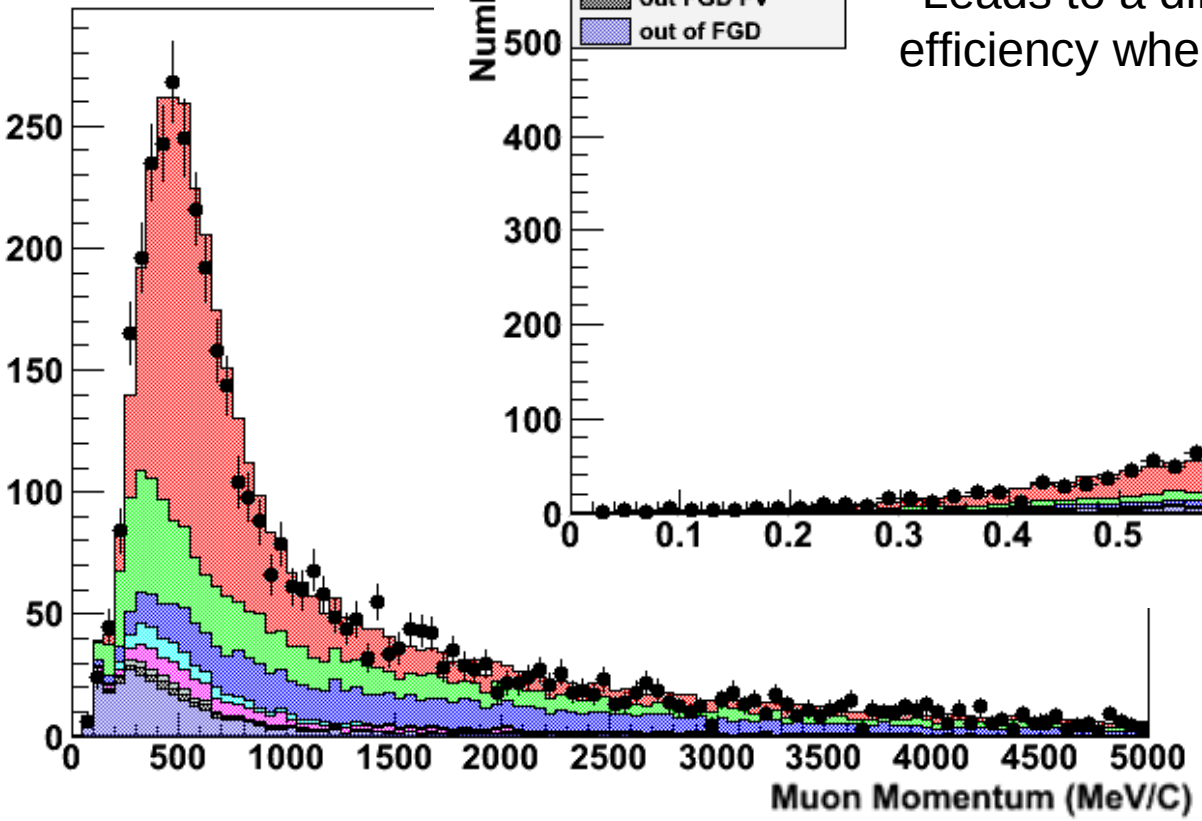
CC-Inclusive p_μ-θ_μ

Preliminary



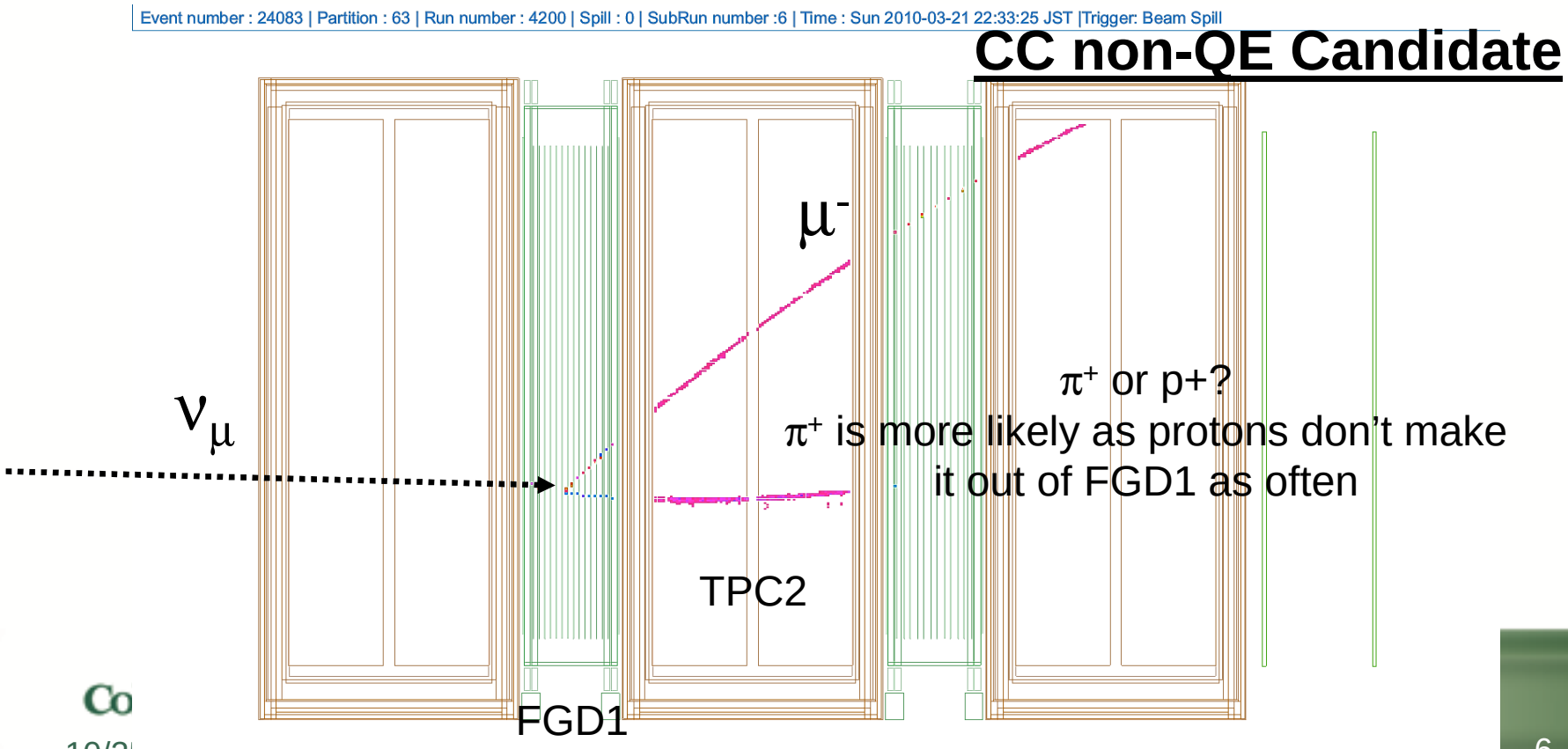
- Accepts mostly forward going muons, low Q^2
- Leads to a different acceptance efficiency when compared to SK

Preliminary



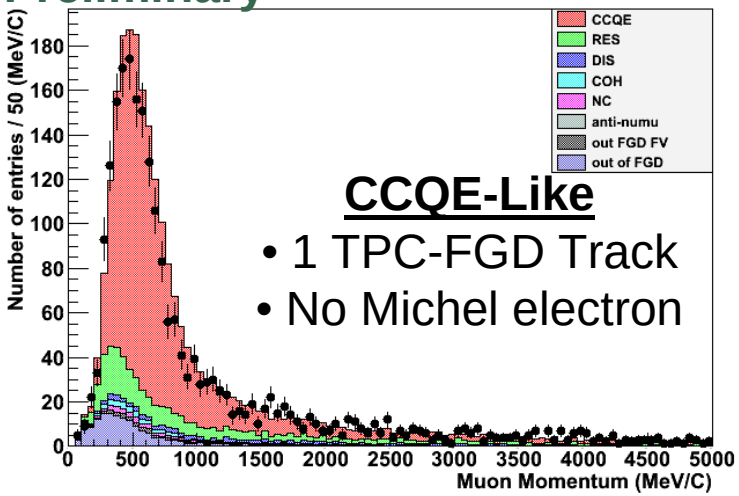
CCQE/CC non-QE Selection

- CCQE selection
  - No second track in TPC2
  - No Michel electron in FGD1
- CC non-QE selection
  - Any extra tracks in TPC2
  - Any Michel electrons in FGD1



CCQE/CC non-QE samples

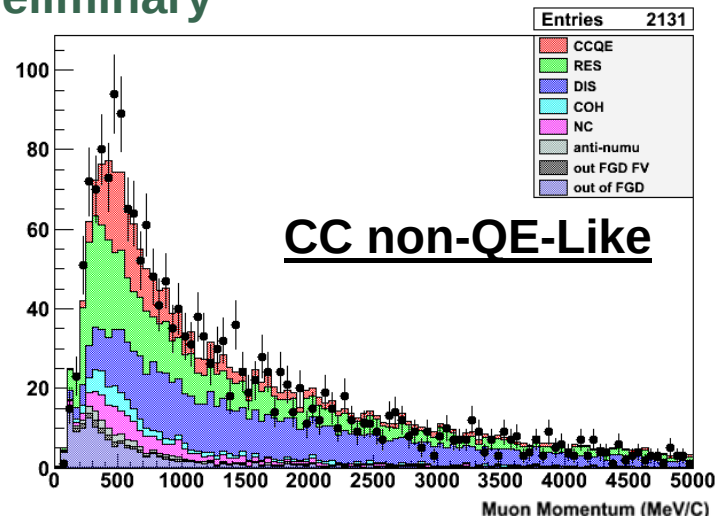
Preliminary



CCQE-Like

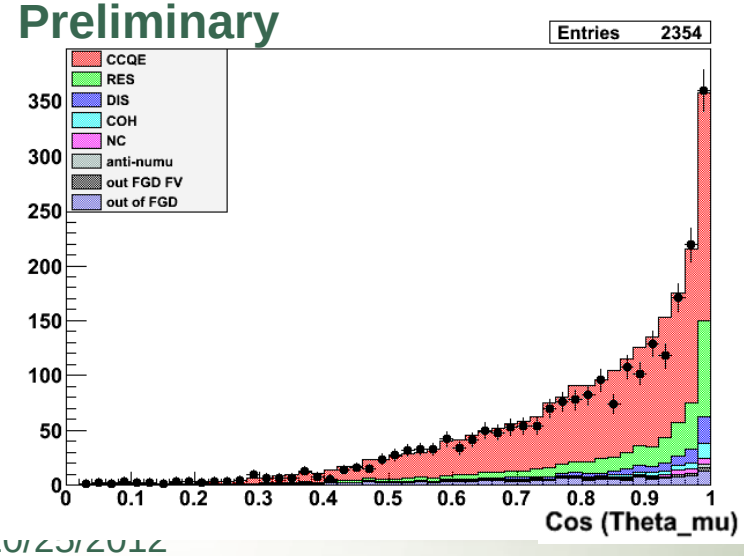
- 1 TPC-FGD Track
- No Michel electron

Preliminary

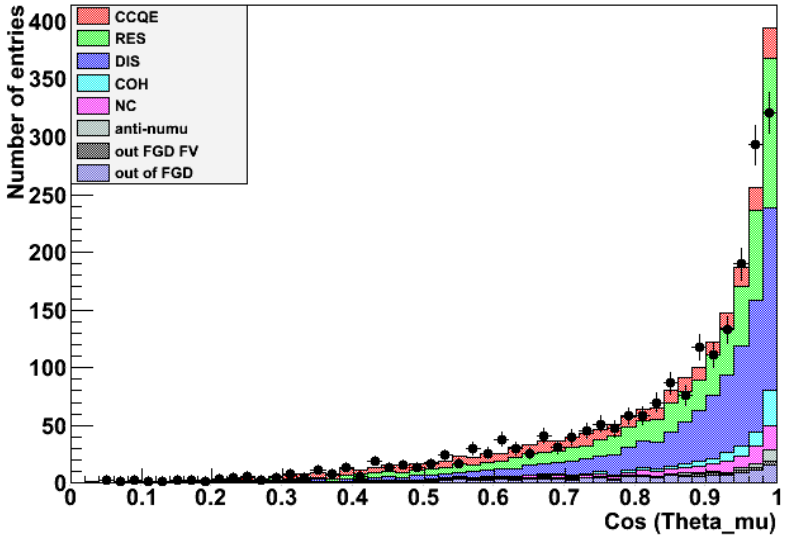


CC non-QE-Like

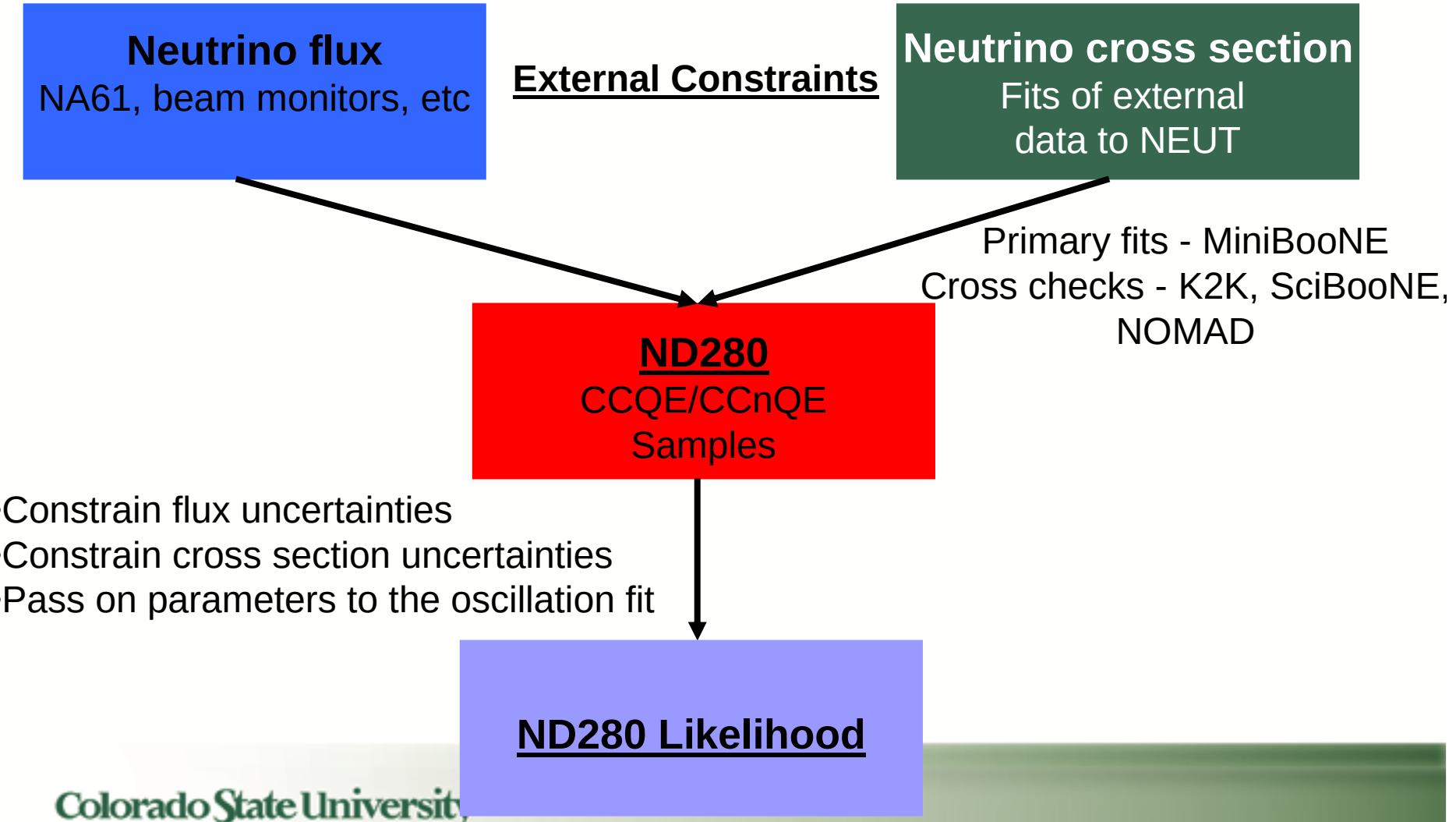
Preliminary



Preliminary



ND280 constraint



Binning and systematics

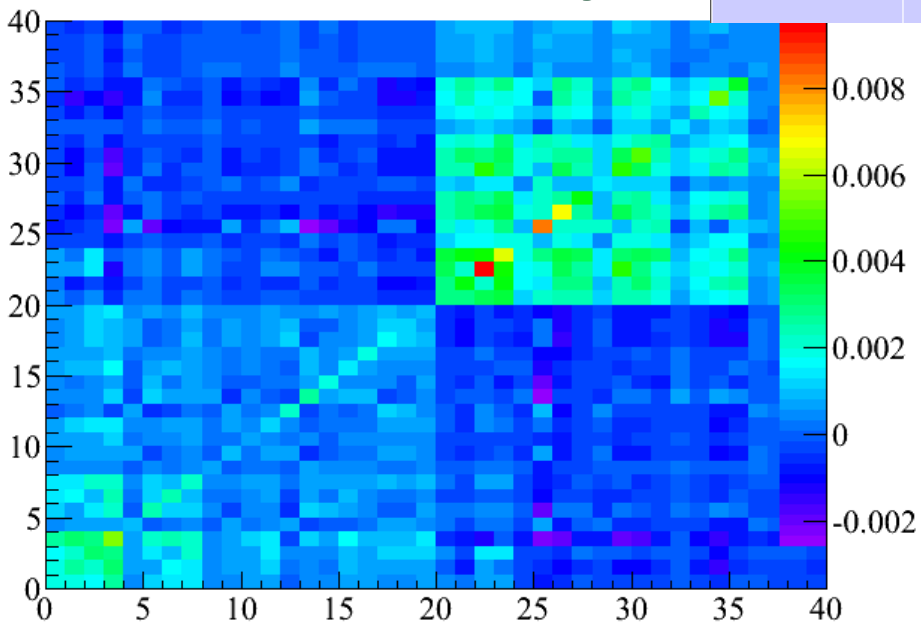
- p-θ binning choice
  - 5 momentum bins and 4 angular bins
    - Have at least ~20 events in a bin
    - Bins are chosen to equalize bin content
    - Detector resolutions must be smaller than the bin size
- Detector systematics are passed to the fit as a covariance matrix with the same binning

Fit Inputs

Preliminary CCQE sub-sample — Data / MC

$\cos\theta_\mu$ \ P_μ (MeV)	0-400	400-500	500-700	700-900	>900
0-0.84	332 (333.76)	247 (266.88)	309 (338.31)	90 (106.84)	95 (96.47)
0.84-0.90	43 (44.40)	41 (46.73)	95 (104.22)	39 (62.71)	66 (84.63)
0.90-0.94	28 (27.55)	29 (30.32)	59 (73.18)	38 (50.89)	93 (107.21)
0.94-1.00	40 (32.01)	27 (33.33)	78 (91.17)	70 (73.63)	535 (538.40)

Detector Covariance **Preliminary**



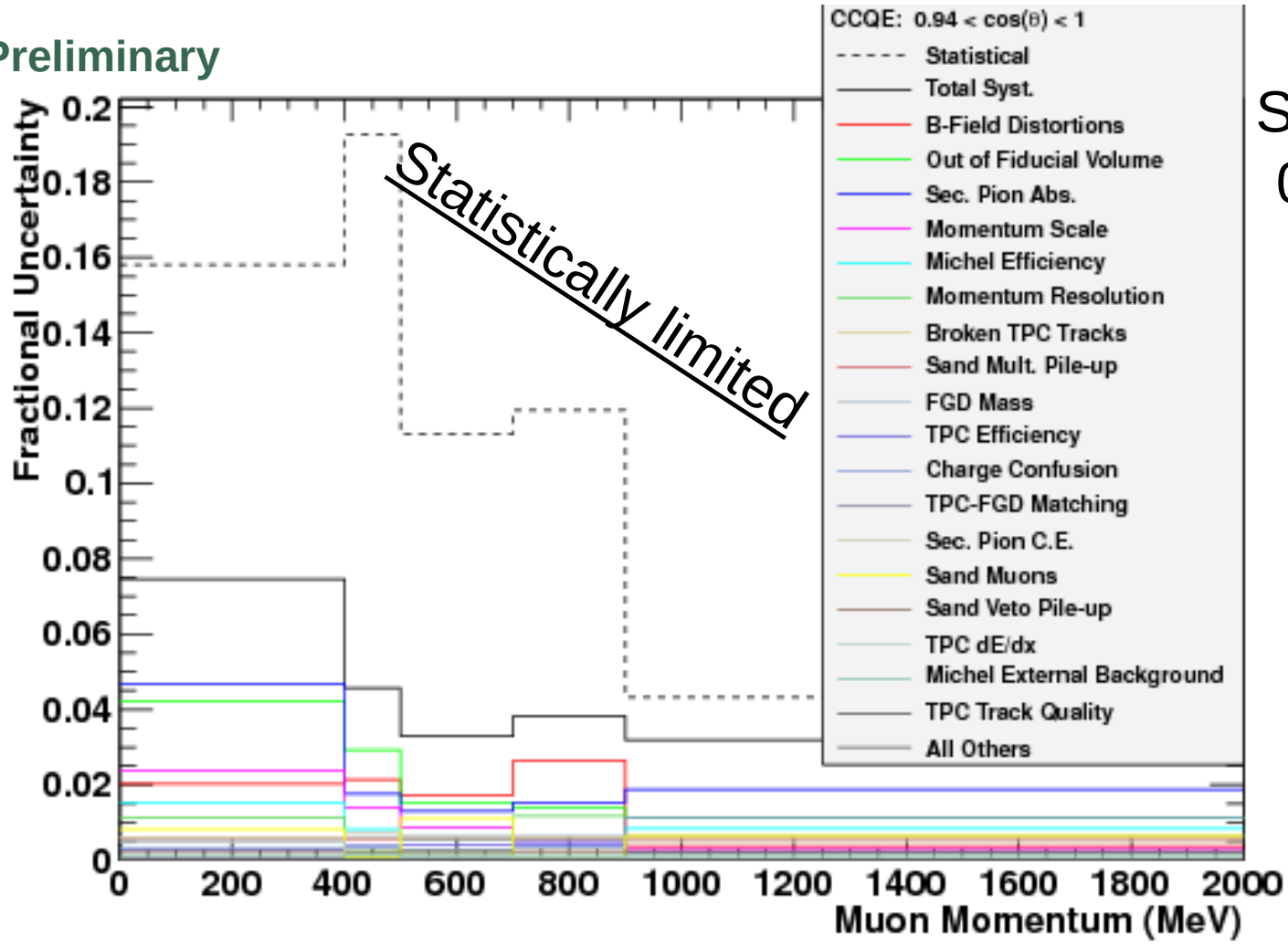
CCQE 0-19, CCnQE 20-39

p-θ binning and event# for data and MC in the CCQE sample (Similar set for the CCnQE)

Detector Systematics

Example Detector Systematics

Preliminary



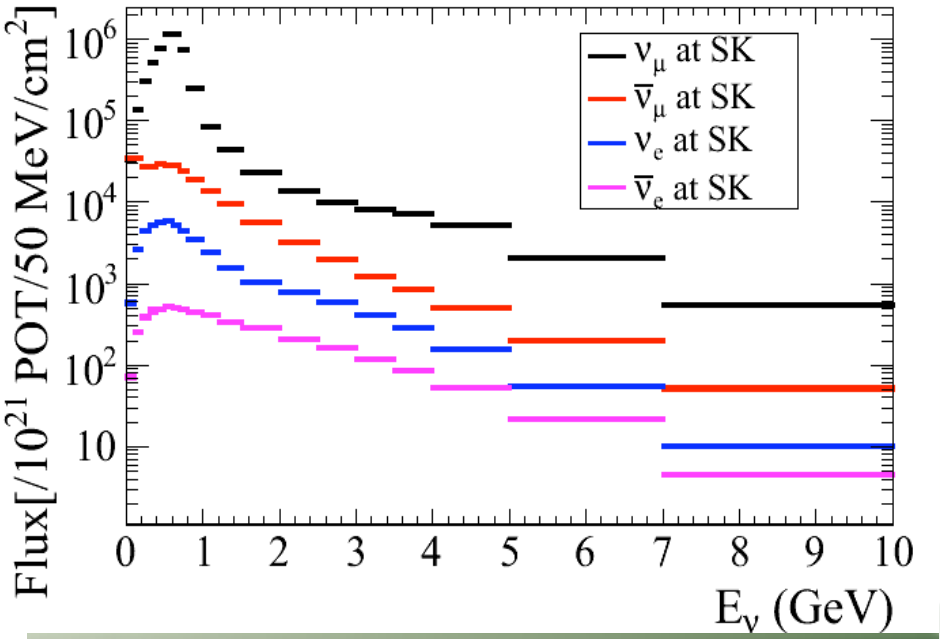
Single angle bin
$0.94<\cos(\theta)<1$

ND280 Constraint Flux

Neutrino flux
NA61, beam monitors, etc

Prior constraints for flux uncertainty

- Provided in the form of a covariance matrix
- Information from beam monitors and NA61
- 11 bins in E_ν for ν_μ
- Normalization in each bin



ND280 Constraint Cross section

	Prior Value and Uncertainty	
M_A^{QE} (GeV)	1.21 ± 0.45	Cross section parameter
CCQE Norm. 0-1.5 GeV	1.000 ± 0.110	Normalization
CCQE Norm. 1.5-3.5 GeV	1.00 ± 0.30	Normalization
CCQE Norm. >3.5 GeV	1.00 ± 0.30	Normalization

Neutrino cross section
Fits of external data to NEUT

Primary fits - MiniBooNE
Cross checks - K2K, SciBooNE, NOMAD

FSI Contributions

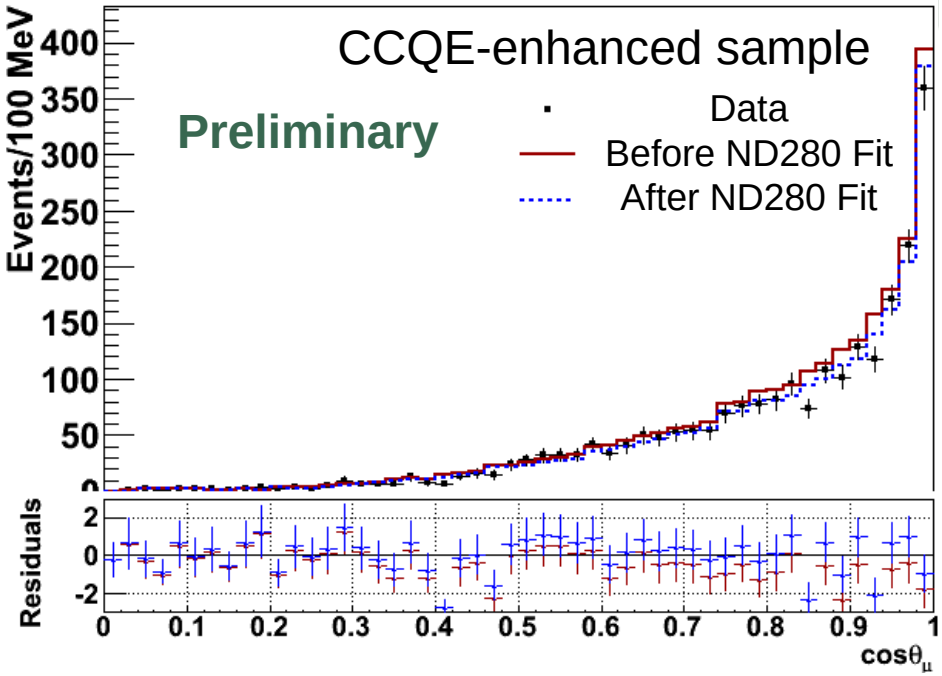
- 16 FSI parameter sets representing 1-σ contours
- Each set is reweighted and bin migration is seen in the p-θ bins of the CCQE↔CCnQE sample
- Covariance matrix is then added to the detector matrix

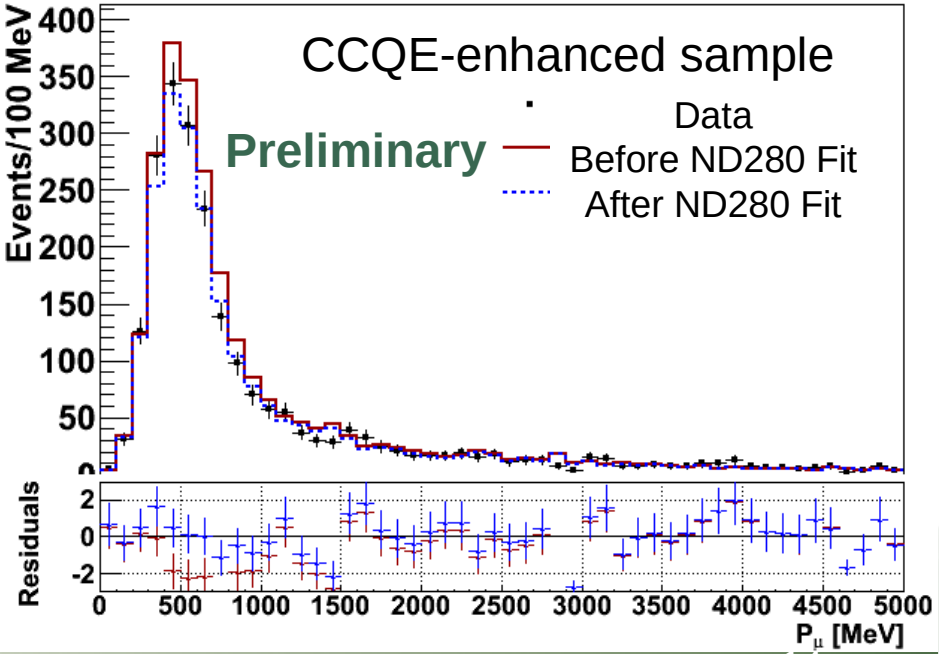
Fitter Results

	Prior Value and Uncertainty	Fitted Value and Uncertainty
M_A^{QE} (GeV)	1.21 ± 0.45	1.19 ± 0.19
CCQE Norm. 0-1.5 GeV	1.000 ± 0.110	0.941 ± 0.087
CCQE Norm. 1.5-3.5 GeV	1.00 ± 0.30	0.92 ± 0.23
CCQE Norm. >3.5 GeV	1.00 ± 0.30	1.18 ± 0.25

Fitted value and uncertainty are propagated to the SK ν_e appearance fit

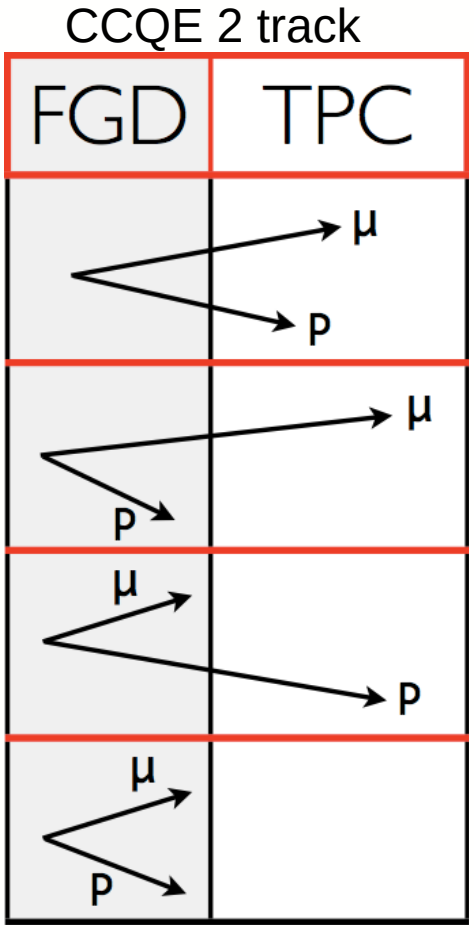
- Reduction in all uncertainties
  - 0.45 –> 0.19 for M_aQE
- Lower the normalization in two lower energy regions
  - 0->1.5 GeV ~6% reduction
  - 1.5->3.5 GeV ~8% reduction



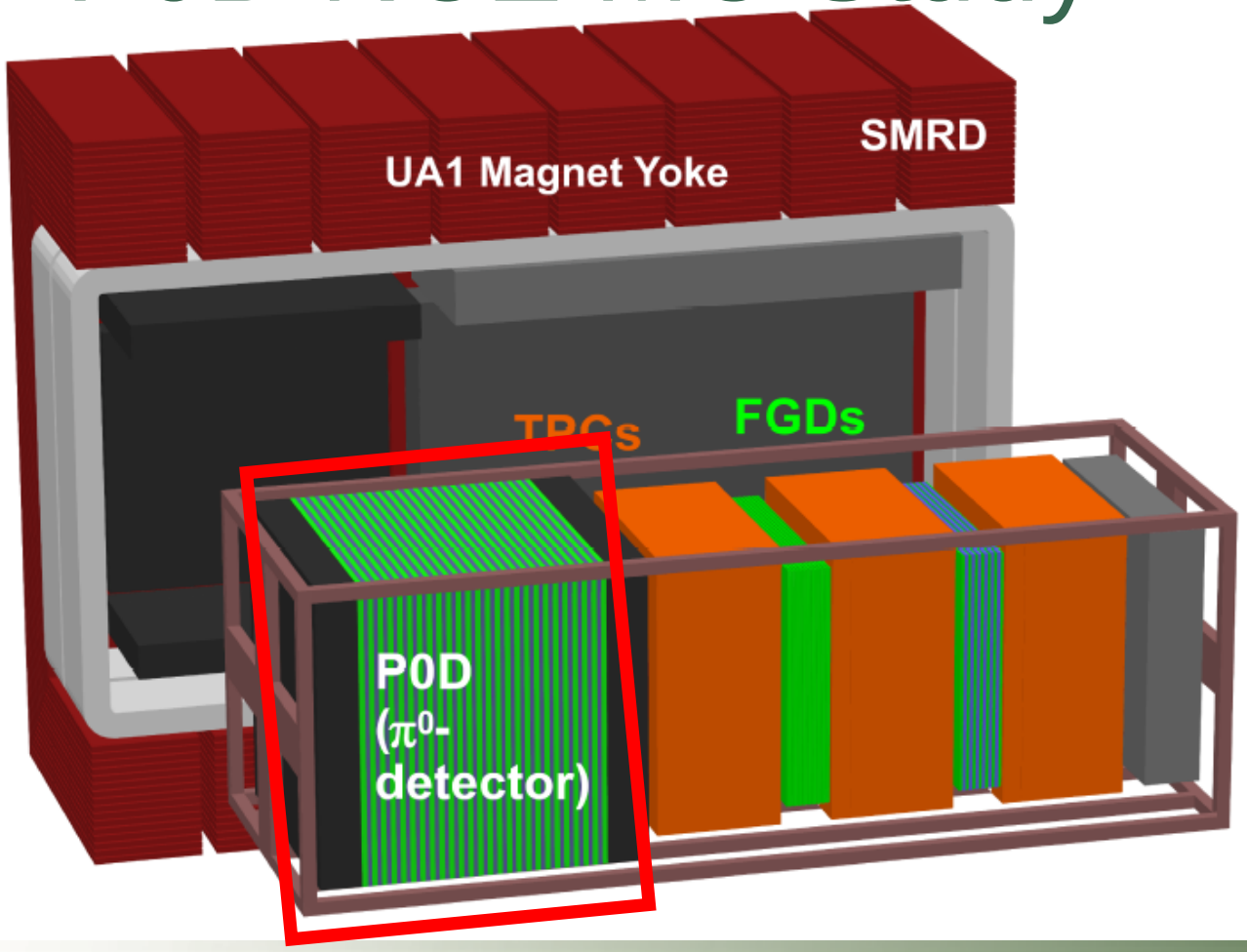


Future work

- Select CCQE based on μ^-+ p^+ topology
  - 2 track samples relying on FGD and TPC PIDs
- Use current CCQE sample to determine M_A^{QE} and energy dependent cross section
- Select CCNπ^+ interactions (See Matt Murdoch's talk)
  - Better understanding of pion bkgs for cross section extraction

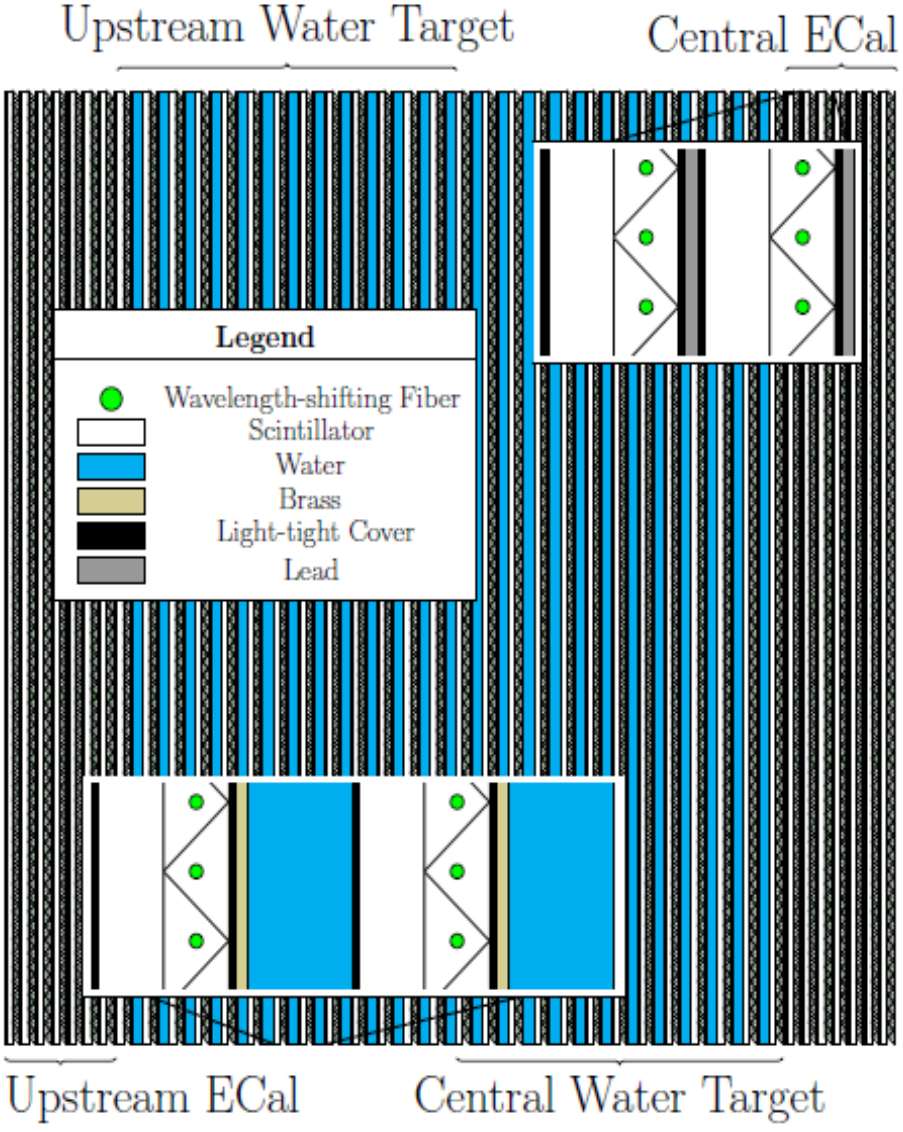


P0D NCE MC Study



π^0-detector (P0D)

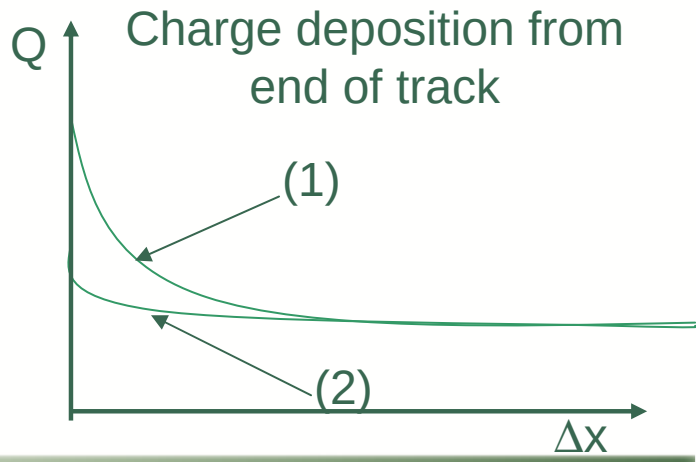
- Partially active volume
- Two EM Calorimeters (ECal)
  - Scintillator + lead
  - Helps contain EM showers
- Two water targets (WT)
  - Scintillator + brass + water(air)
  - Removable water to provide measurement of neutrino cross-sections on water
  - Brass to help initiate EM showers



P0D Analysis Scheme

- Trying to extract the NCE neutrino interaction
  - Signal
    - (1) consists of a forward going proton contained in P0D
  - Background
    - (2)consists of single track CCQE
    - (3)CCQE with a backwards going μ^-

Mis-reconstructed as single track



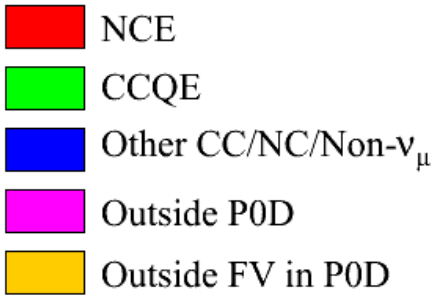
Analysis Goals

- Finalize event criteria for both water-in and water-out configuration
- Using data from water-in and out extract NCE cross section on water
- Can also look at other heavy nuclear targets: Zn+Cu, C, Pb (in ECal sections)
- This presentation has MC predictions for the water-in configuration scaled to data protons on target (POT)

Analysis cuts

- Require 1 reconstructed vertex with 1 3D track
- Require start of the track to be within the fiducial volume
  - 25cm from active edges in water target (XY cut)
  - Within readout planes in the water target (Z cut)
- Require the end of the track be at least 1cm from the active edge of the P0D
- Require downstream end PID of track be non-muon like
  - Current cut results in 82% of the selected tracks having a proton at the downstream end.
- Require upstream end PID of track be non-muon like
- Require 0 Michel clusters

FSI Definitions



NCE: Any interaction where there is a ν_μ but no mesons exiting the interaction nucleus. Any number of protons and/or neutrons are allowed in the final state.

CCQE: Any interaction where there is a μ^- but no mesons exiting the nucleus.

CC Other: Any interaction where there is a μ^- but any number of mesons exiting the nucleus.

NC Other: Any interaction where there is a ν_μ plus some number of mesons exiting the nucleus.

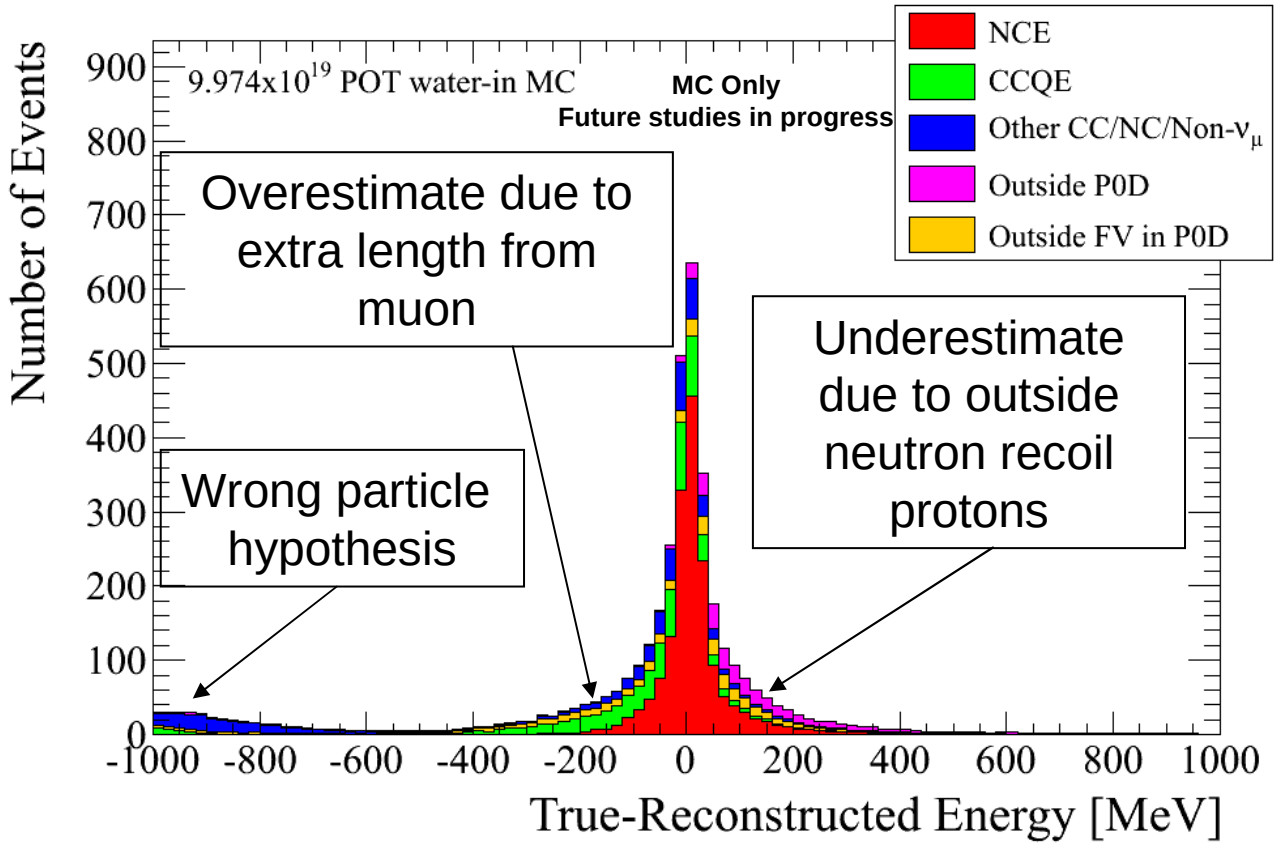
Other: Any non-ν_μ neutrino interaction

Outside P0D: Any interaction with a ν_μ of any interaction type that occurs outside the active volume of the P0D.

Outside FV in P0D: Any interaction with a ν_μ of any interaction type that occurs within the active volume, but outside the FV of the P0D.

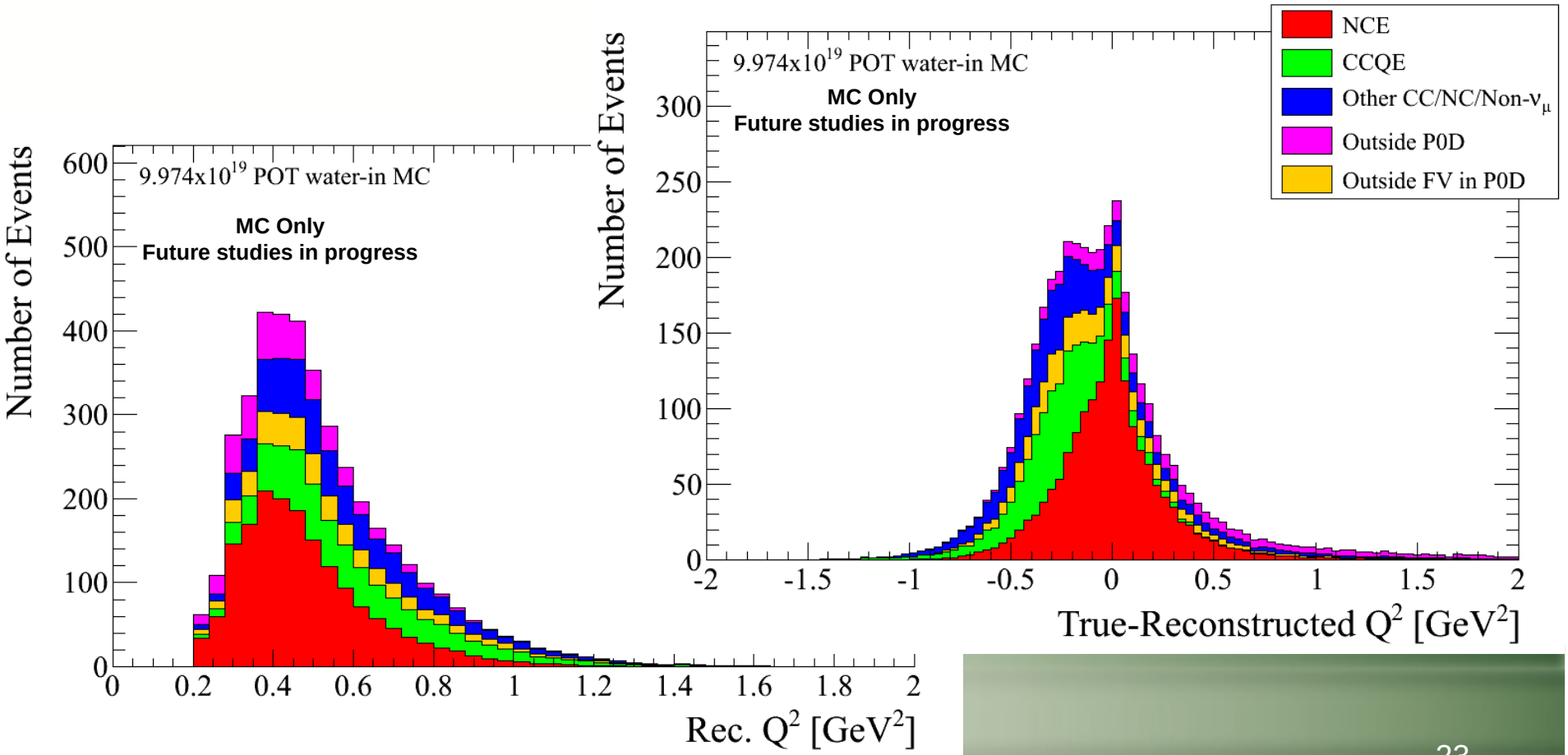
Momentum Reconstruction in the P0D

- Integration of $\langle dE/dx \rangle_{loss\ p}$ of material traversed according to Bethe-Bloch and other corrections

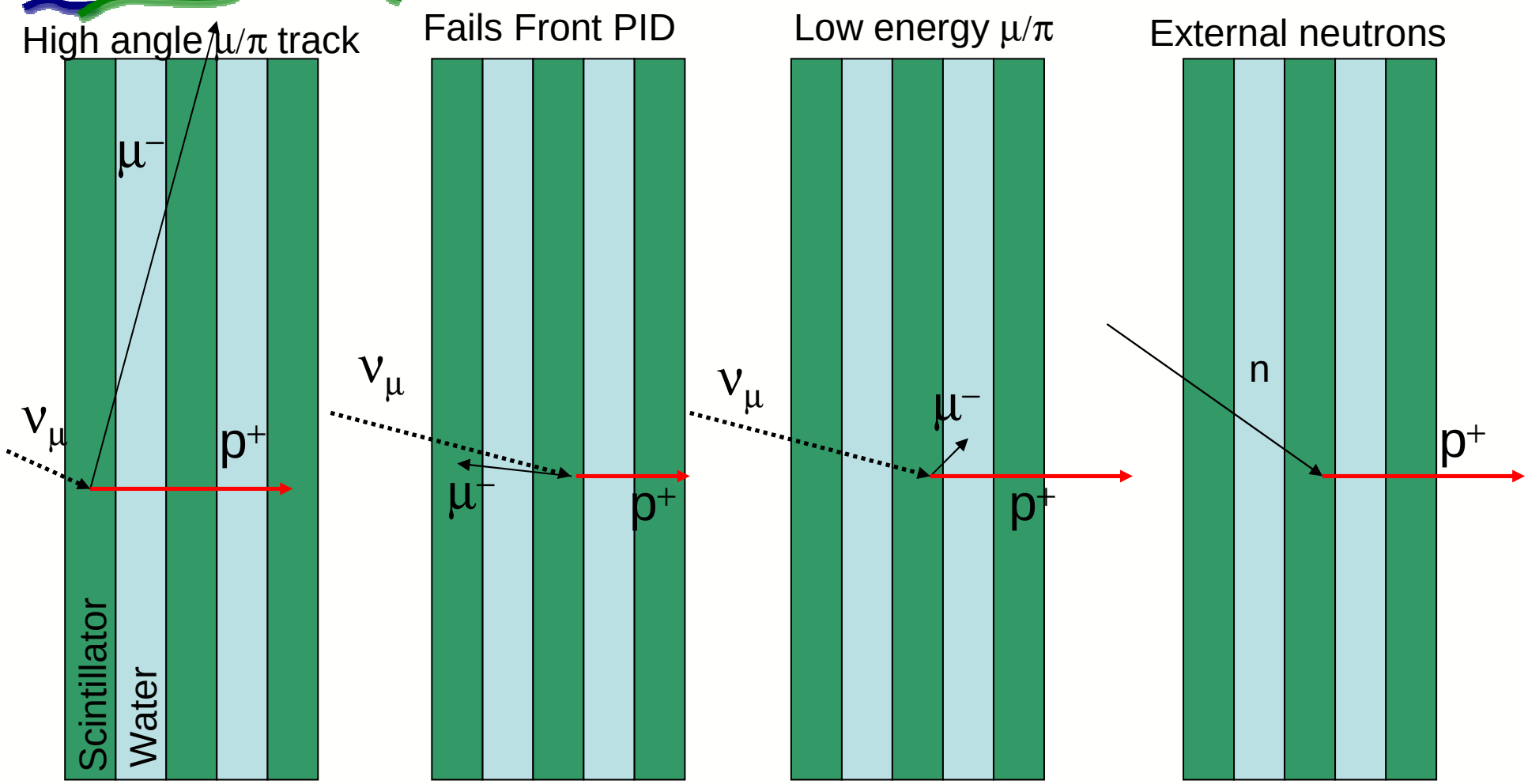


Q^2 reconstruction

- Assumes stationary target $Q^2 = 2m_pT_p$



Example Backgrounds



P0D NCE

- Current water-in selection MC predicts a 14% efficiency and 41.8% purity
  - Scaled to data, 9.974×10^{19} POT
  - ~4000 events with ~1700 NCE events selected
- On going studies to determine how much of the backgrounds are irreducible
- Outside neutron studies are being undertaken, should be as data driven as possible

Conclusions

- Current CCQE result
  - T2K CCQE selection has been used to further constrain the flux uncertainties and cross section parameter uncertainties
- Future CCQE
  - Future work with CCQE will search for μ^-+p^+ topologies using TPC and FGD PIDs
  - Using the current CCQE selection fit in E_ν bins for M_A^{QE}
- Future NCE
  - Continue development of P0D based analysis
  - Study current backgrounds in selection to understand what is irreducible
  - Study outside neutron background in as much of a data driven way as possible

Obrigado!

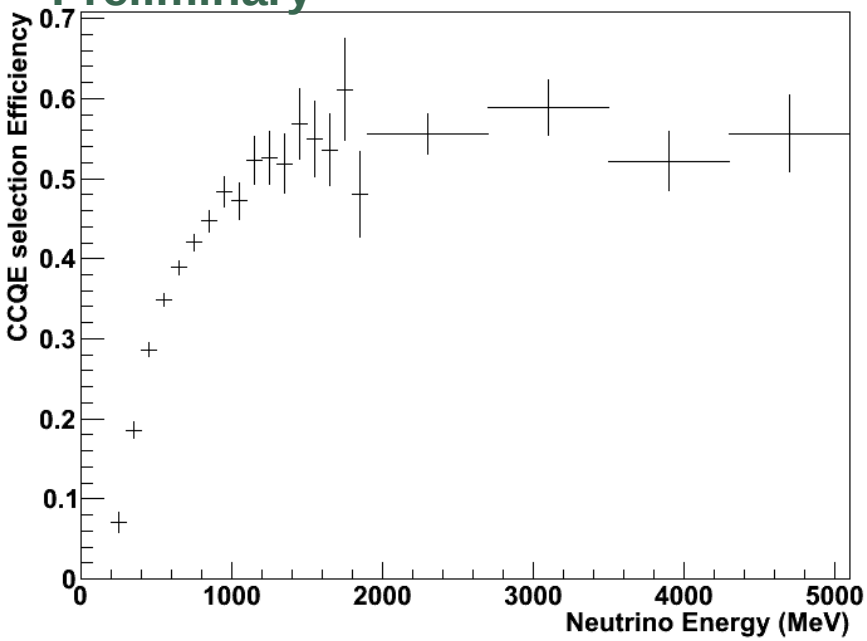
CSU PRSE
for travel funding

NuInt Organizers for their invitation and financial support

Backups

Eff. Pur.

Preliminary



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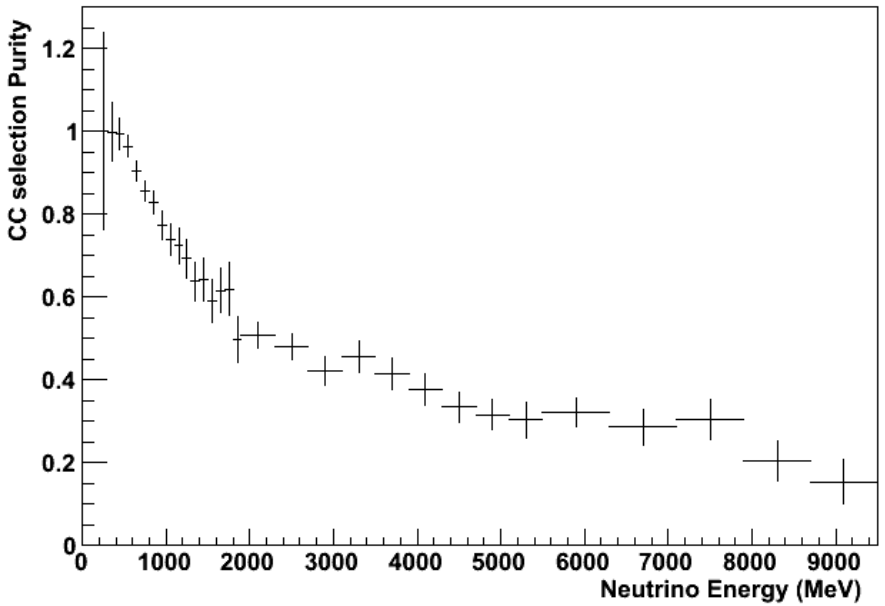
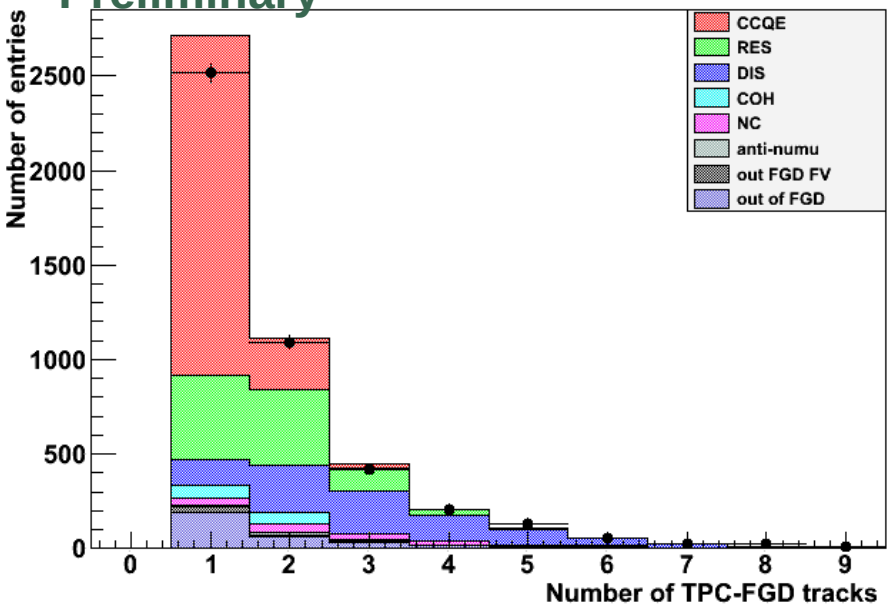


CCQE cuts

Preliminary



Preliminary